REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

3. REPORT TYPE AND DATES COVERED
Final Report 1 Oct 1993 to 30 Sept 1996

4. TITLE AND SUBTITLE
Sheetflow Sediment Transport

5. FUNDING NUMBERS
N00014-94-1-0014

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Code 321CD Department of the Navy
Ballston Towers One, 800 N. Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
No limitations

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Long-term goals are to understand the physics of sediment transport by waves and currents and to use that understanding to predict the bathymetry and sedimentology of the nearshore. Continued development, refinement, testing and production simulations were conducted using a discrete-particle computational model for sheetflow sediment transport. The model simulates the motion of individual solid particles immersed in a rapidly shearing viscous fluid, in which momentum transfer is dominated by solid-particl Simulations successfully reproduce patterns of sorting (segregation of grains by size and density) observed in the nearshore; in particular, grain-size distributions become increasingly coarse in the on-shore direction. Fine-grained layers analogous to laminations form in the simulations at depths within the bed corresponding to the maximum extent of bedload motion. Comparison of simulation results with sedimentary structures in cores taken during the Duck94 Nearshore F 1) Fine sands at Duck may not meet model assumptions for collision-dominated transport, and should be addressed in future models. 2) Non-planar bed configurations, principally megaripples, appear to persist (metastably?) under hydrodynamic conditions thou Thus determining the origin and stability of megaripples is critically important to predicting transport and bathymetric evolution.

14. SUBJECT TERMS
Sediment transport, nearshore, surfzone, computer simulation, boundary layer

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)

19970417 038

Final Technical Report on "Sheetflow Sediment Transport"
ONR Grant No. N00014-94-1-0014
Principal Investigator: Thomas G. Drake

Abstract

Long-term goals are to understand the physics of sediment transport by waves and currents and to use that understanding to predict the bathymetry and sedimentology of the nearshore. Continued development, refinement, testing and production simulations were conducted using a discrete-particle computational model for sheetflow sediment transport. The model simulates the motion of individual solid particles immersed in a rapidly shearing viscous fluid, in which momentum transfer is dominated by solid-particle interactions. Simulations successfully reproduce patterns of sorting (segregation of grains by size and density) observed in the nearshore; in particular, grain-size distributions become increasingly coarse in the on-shore direction. Fine-grained layers analogous to laminations form in the simulations at depths within the bed corresponding to the maximum extent of bedload motion. Comparison of simulation results with sedimentary structures in cores taken during the Duck94 Nearshore Field Experiment indicates several avenues for further investigation: 1) fine sands at Duck may not meet model assumptions for collision-dominated transport, and should be addressed in future models; 2) non-planar bed configurations, principally megaripples, appear to persist (metastably?) under hydrodynamic conditions thought to produce sheetflow laminae. Thus determining the origin and stability of megaripples is critically important to predicting transport and bathymetric evolution.

Introduction

The long-term goal of this work is to understand in detail the physics of sediment transport by waves and currents and to use that understanding to predict the bathymetry and sedimentology of the nearshore. A secondary goal, the inverse of the first, is to interpret the environment of deposition and the offshore wave climate from the sedimentary record.

A discrete-particle model for flowing granular materials, modified to incorporate a viscous interstitial fluid, was used to simulate intense bedload transport (sheetflow) in the nearshore. A second element of the research is comparison of simulation results with sedimentary structures in three-inch-diameter cores obtained as part of the Duck94 Nearshore Field Experiment conducted Fall 1994 at Duck, North Carolina. The following sections first introduce the topic of high-concentration bedload transport, briefly describe the field experiment and collaborative effort with other Coastal Dynamics Program investigators, and summarize the results of the field/simulation comparisons.

Background

Particle-scale information necessary to formulate, test, and refine theories for bedload transport and resultant sedimentologic and bathymetric evolution in the nearshore environment is exceedingly difficult to obtain. Of particular interest are high sediment transport rates and concomitant rapid bathymetric evolution associated with storm-generated waves and currents. Such conditions typically prevent all but gross field measurements of bed elevation and fluid motion, not to mention sediment transport rates. Likewise, laboratory observations under field-relevant conditions are rare, as relatively few experimental facilities can generate long-period, high-velocity oscillatory flows. This study uses discrete-particle computer simulations to describe the bedload motion of individual sediment particles under a restricted but highly relevant range of nearshore flow conditions: intense, collision-dominated near-bed or bedload transport of coarse sand and larger grains.

Large surface gravity waves in shallow water generate intense bedload transport commonly called *sheet flow transport*, which is thought to be a primary agent in nearshore bathymetric and sedimentologic evolution. Available field and laboratory observations of sheet flow indicate that bedload motion is confined to a relatively thin (up to several cm), nearly horizontal layer of moving grains having a distinct upper surface. Under sheet flow conditions the bed remains nominally planar, and thus roughly corresponds to the upper flow regime in unidirectional flows. The

absence of ripples and other bed topography greatly simplifies description of the bulk fluid motion. Sheet flow is thus a theoretically attractive two-phase turbulent flow, and as such has generated a considerable body of theory and observation in a number of disparate fields. Theoretical work on collision-dominated bedload transport derives from the work of Bagnold (1954).

Discrete-particle models for high-concentration bedload transport

Fully three-dimensional discrete-particle computer simulations of high-concentration bedload transport of spherical grains in oscillatory flows provide detailed quantitative information difficult or impossible to obtain from physical experiments. Such information, particularly fluctuations in particle velocities, plays a critical role in recently developed theories for dense sediment transport, in which momentum is transferred primarily by collisions between particles. The simulation integrates F=ma and a corresponding set of equations for the torques for each sphere. Normal and tangential forces between contacting particles are linear functions of the distance between sphere centers and the relative tangential displacement at the contact point, respectively; particle interactions are both inelastic and frictional (Drake and Walton, 1995). The simplest fluid model specifies the oscillatory motion of the uppermost layer of a stack of thin horizontal layers of fluid that exchange momentum by either a molecular viscosity or a time-varying eddy viscosity and exert fluid forces (drag, added mass and buoyancy) on particles.

Previously we obtained high-speed motion pictures of bedload transport of 6.5-mm-diameter plastic spheres in a unidirectional flow and simultaneously measured the fluid velocities within the bedload layer using a laser-doppler velocimeter (Drake et al., 1991). These observations using identical spheres having known material properties provide a stringent means of testing our discrete-particle computer model. Comparison of simulation results with the unidirectional laboratory experiments using identical plastic spheres show the simulations are insensitive to details of the force laws for particle contacts (Drake, 1992). Furthermore, the bulk properties of the simulated granular-fluid assemblage are robust to large variations in material properties of the particles.

Further results from a bedload simulation of quartz-density spheres having a mean diameter of 1mm in a sinusoidal oscillatory flow having a 4s period and a 2 m/s maximum free-stream fluid velocity, such as might be generated in a laboratory flow tunnel (i.e. King, 1991), were compared to existing experimental data. The simulations are in good agreement with bulk transport rates measured by King (1991) and also predict the maximum depth of bedload motion, in agreement with experiments conducted by Gallagher and Seymour (1992) in the same flow tunnel as that used by King (1991). The simulations predict a great deal of additional bedload phenomena, but there are presently no experimental or field data available for comparison. For instance, the maximum instantaneous bedload transport rate lags the maximum free-stream velocity by about 50 degrees; and the bulk of the transport occurs within a high-concentration region (greater than 0.1 by volume) of the bedload layer.

Of great interest to field studies are simulations of intense sheetflow transport induced by an asymmetric velocity field comparable to that produced by non-breaking shoaling waves. Our simulations show strong net onshore-directed transport, and preferential onshore transport of coarser grains. The effect of flow accelerations on bedload transport is generally non-negligible, and is an area of on-going study. A principal concern is providing field-measurable input to the simulations, so that a greatly-needed synergy between field and simulation studies can be established.

Finally, a general feature of all bedload simulations in the sheet-flow regime is the development of so-called "inverse grading," in which the larger grains tend to accumulate at the top of the bedload layer. Development of grain-size segregation analogous to laminae in the simulations is a feature unique to discrete-particle simulations, and forms the basis for comparison with sedimentary structures obtained in field studies of cores collected during the Duck94 Nearshore Field Experiment, in conjunction with work supported by the US Army Engineers Waterways Experiment Station Field Research Facility at Duck, North Carolina.

Simulation Results and Sedimentary Structures

Few studies of sedimentary structures in the nearshore have been undertaken and none have had the benefit of the substantial supporting studies conducted during the Duck94 experiment, in particular, a cross-shore transect of instruments designed to provide measurements of water depth, bed elevation, and cross- and alongshore components of nearbed water velocity at a frequency of 2 Hz for the duration of the Duck94 experiment. Observations of these fundamental fluid-dynamic quantities, provided by ONR Coastal Dynamics Program investigators R.T. Guza and S. Elgar of the Center for Coastal Studies, Scripps Institution of Oceanography, University of California at San Diego, form the basis for relating sedimentary structures from sediment cores obtained using the FRF's CRAB.

Sedimentary structures observed in the cores, in particular, bedding planes or other evidence of stratification, are generally rather poorly correlated with synthetic stratigraphies generated from sonic altimeter observations of bed elevation. In a few particular cases, however, the correlation between structures observed in cores and sonic altimeter observations is good, and may offer useful means for using structures from cores to retrodict the wave climate responsible for their formation, or vice-versa. The principal results and implications for comparison of simulation results with field observations of sedimentary structures are described below.

First, the field observations of sedimentary structures and associated hydrodynamic data indicate that our understanding of the parameter space under which sheet flow occurs is quite incomplete. In particular, cores extracted from the crest of a newly-deposited bar formed entirely during the course of the Duck94 experiment show unequivocally that offshore bar migration occurred by the onshore migration of megaripples from deep water onto the offshore side of the bar, while unknown processes eroded the onshore side of the bar. Evidence for megaripple-induced bar migration is in the form of onshore-dipping cross-bedded sand layers preserved in the cores, which can only result from grains avalanching down the slipface of an onshore-migrating bedform. Such deposits are completely unlike the horizontal laminae generated by sheetflow transport.

Yet prevailing hydrodynamic conditions throughout the bar-migration episode were favorable for sheetflow transport, according to previous observations (e.g. Dingler and Inman, 1976). The most probable explanation(s) are that sheetflow and megaripples coexist in the same stability fields: sheetflow conditions occur on the relatively planar, horizontal stoss slopes of megaripples. Alternatively, or in addition, megaripples appear to persist under conditions that might be unfavorable for their genesis. Thus much of the depositional evidence expected to contain horizontal sheetflow laminae on the basis of hydrodynamic data and information from previous studies, instead contains deposits generated by migrating bedforms.

Cores displaying horizontal laminae for which hydrodynamic data are available are few. The thickness of preserved laminae in these cores is consistent with simulation results, but correlations between observed structures and the simulations are somewhat unsatisfying, for the following reasons:

First, simulations indicate the thickness of laminae is not highly sensitive to various parameterizations of the hydrodynamic conditions, for instance, the maximum instantaneous orbital wave velocity. Second, the true original laminae thickness is difficult to determine, because subsequent waves may remove part (or all) of any existing laminae before its preservation by burial. Third, the grain-size distribution of sands at Duck study site is dominated by fine sands, for which the simulation assumption of collision-dominated momentum transfer between grains may be violated.

In summary, the simulations reveal a wealth of information that will be incorporated into future sediment transport studies. The observations 1) call into question the efficacy of the Bailard (1981) and Bowen (1980) models, neither of which addresses fluid accelerations in their prediction of sediment transport in the surf zone. Processes of grain-size and density segregation are important to meaningful interpretation of sedimentary evidence, and to studies of swash-zone processes, where gradients in grain size can be large and important. Finally, this research points to the need for considerably more work on fundamental sediment-transport processes, in particular, the mechanics of megaripple migration.

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